INFORMATION NEEDED FROM GMD FORECASTERS

Space Weather Workshop, Boulder, CO – April 2015

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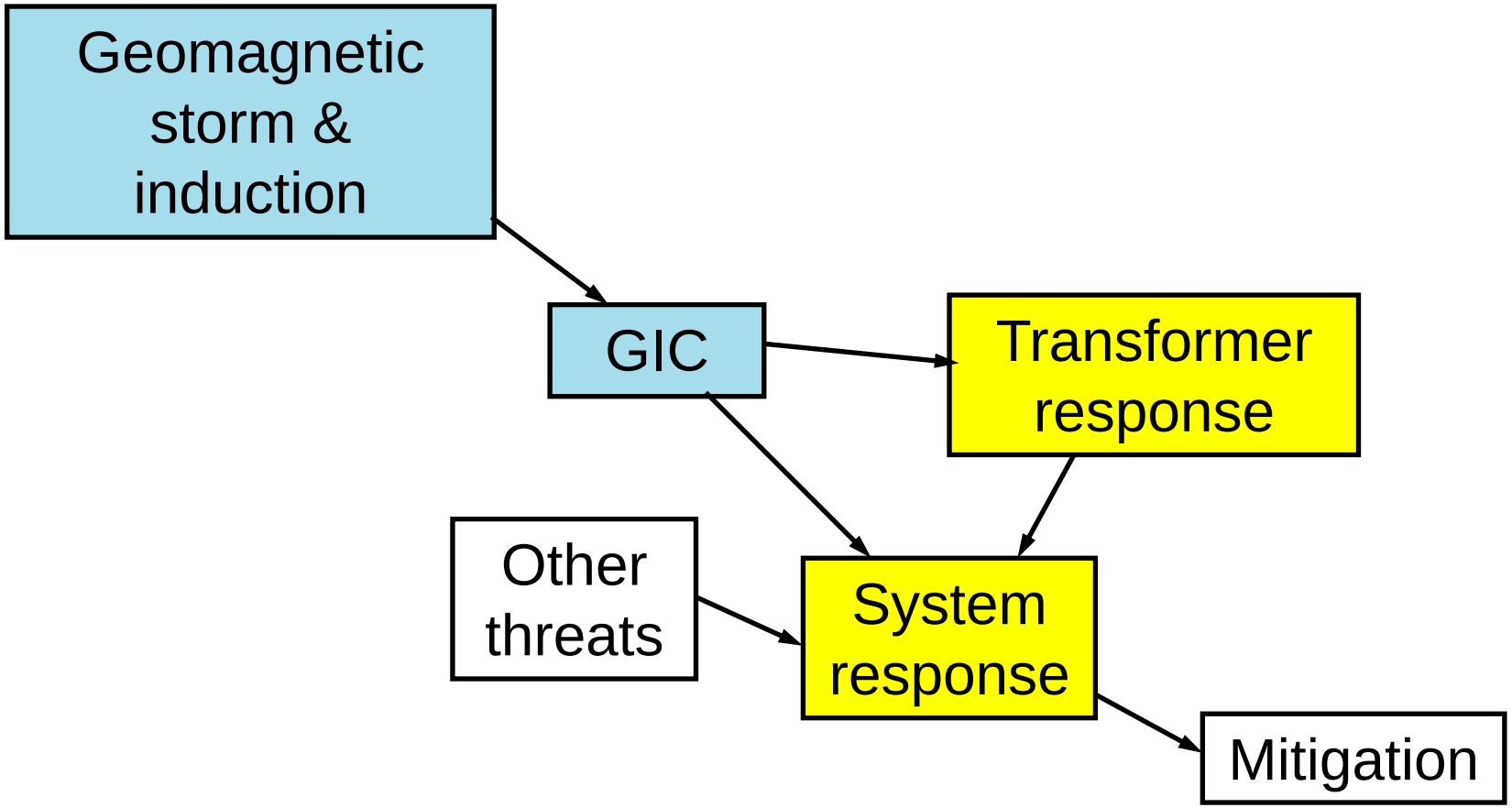
University of Cape Town

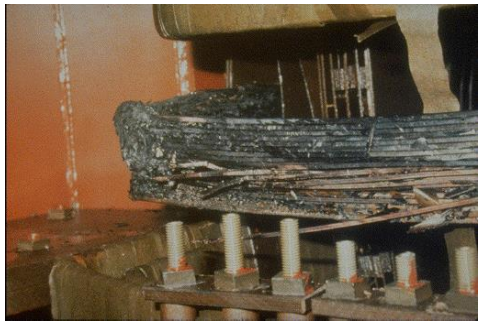
Engineering exposure



GIC risk in power systems

Risk of immediate power system collapse. (Hydro Quebec, Malmö)

Risk of immediate transformer failure, without causing system collapse. (Salem, National Grid)



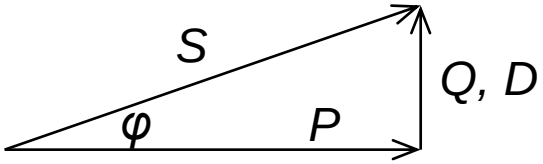
Risk of damage to transformers, not immediately evident. (Allegheny Power, Eskom)

Power Calculations

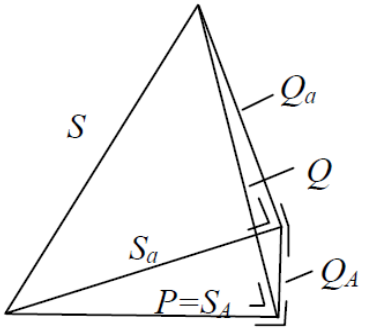
- $S = E_1I_1+E_2I_2+E_3I_3$

where E, I = rms values of e and i over cycle

- $S^2=P^2+Q^2+D^2$, p.f. = P/S
- Balanced 3-phase systems with harmonics



- Linear algebra integration
- $S^2=P^2+Q^2$, p.f. = P/S where $O^2= Oa^2 +O_A^2$



- Distortion, unbalance, DC, and losses in neutral

Conventional Theory

General Power Theory

Power factor (p.f.) is a measure of relative efficiency of power delivery

Risk of system collapse

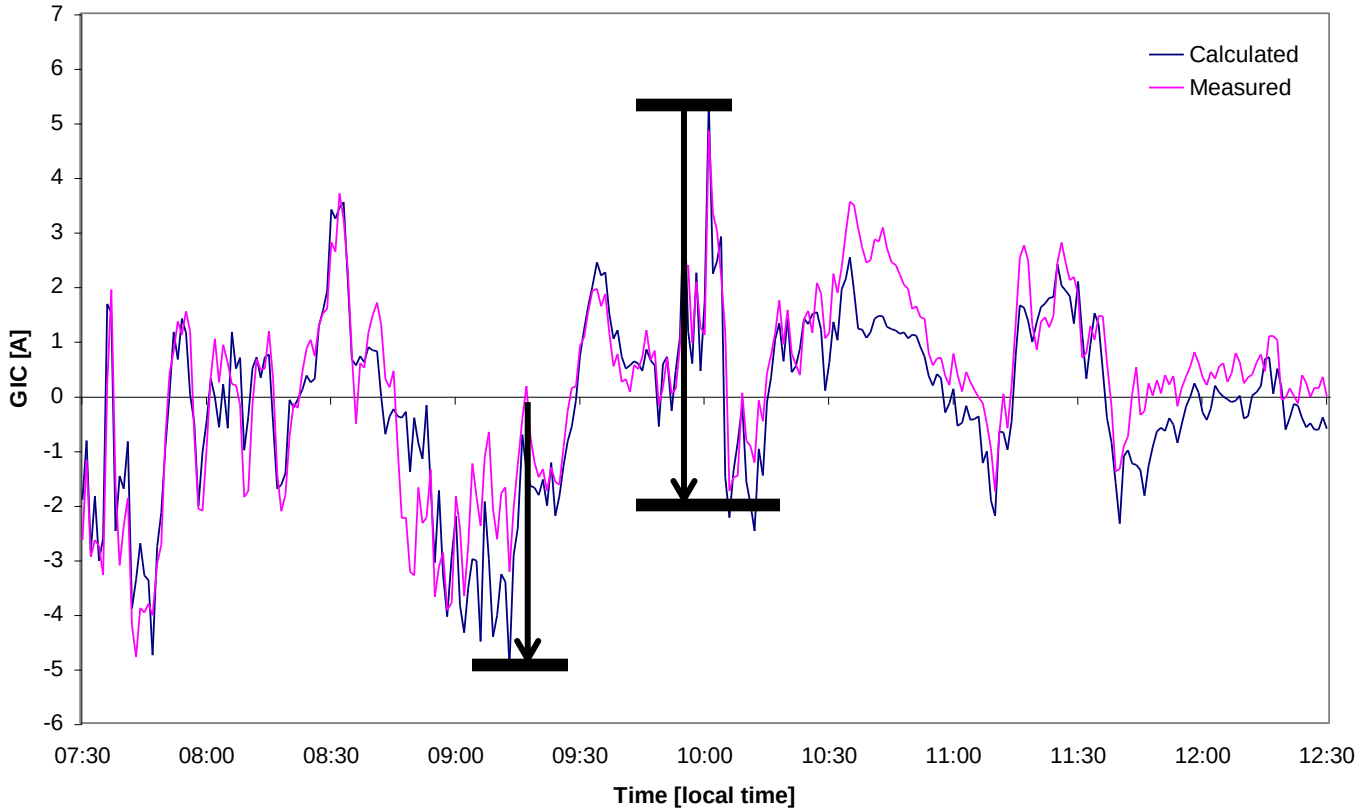
Non-active power Q is absorbed by transformers carrying GICs

Voltage instability models (valid software, accuracy threshold)

Equipment response to dc and harmonics: capacitors, instrument transformers and protection relays

Common mode failure: communications, protection and voltage swings

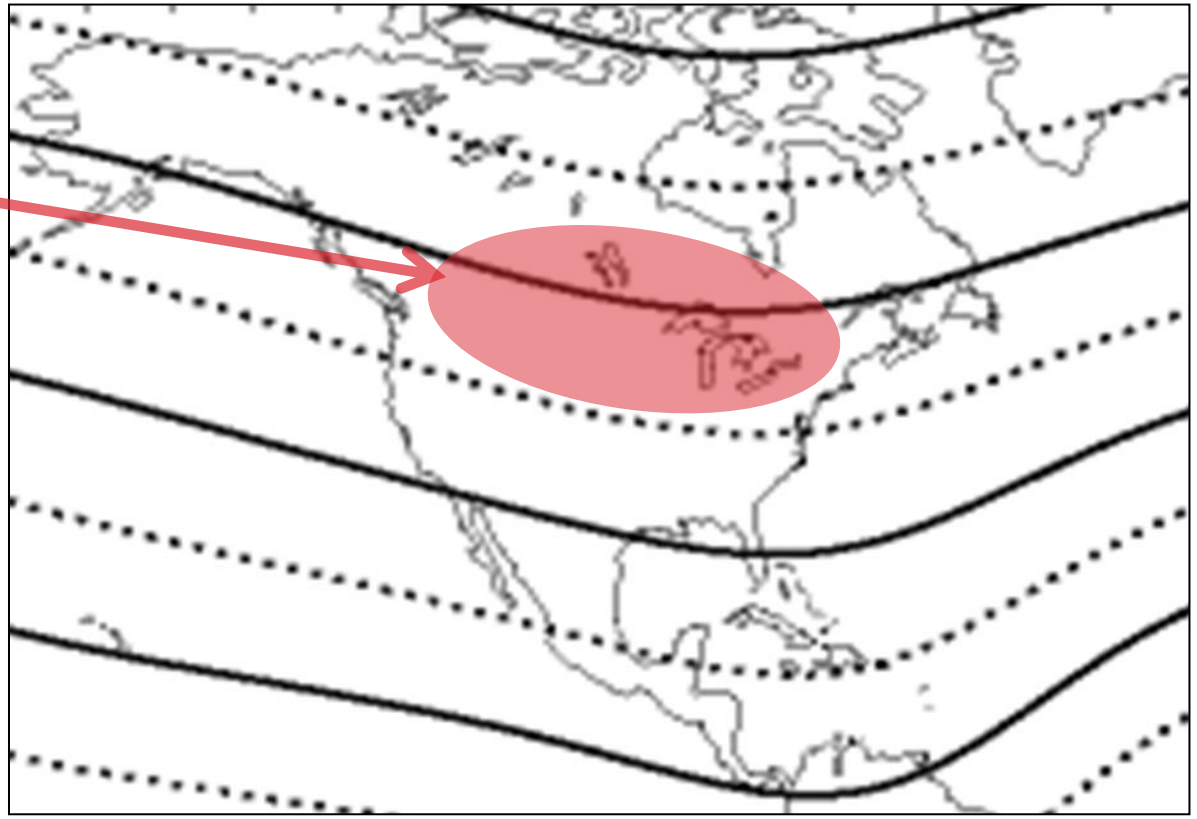
Peak GIC → Instability



Magnitude and rate of change of GMD/GIC – extreme values and extreme fluctuation

Risk zone

Extreme events:
system collapse



Expectations of collapse-GMD

Very large, geo-effective CME.

Probably fast, possibly multiple CMEs.

Mitigation: by reducing load on long lines, increasing non-active power capacity.

Want to know:

- 18 / 18 / 18 warning (days/hours/minutes)
- Location (longitude and latitude)
- Time of arrival (with certainty)
- Peak intensity

Immediate transformer failure

Conditions similar to collapse risk

Mitigation: Demand reduction on key transformers, (future) adaptive relaying for power factor correction equipment

Want to know:

- Same GIC forecasts
- Heating response of transformers
- Vulnerable transformers

Delayed equipment damage

Transformers

Reactors

Generators – through the transformers

Harmonics, unbalance, variable leakage fluxes, overheating

Cumulative and progressive failure models

Report to Sunburst – Sep 2004

TRANSFORMER DAMAGE IN ESKOM NETWORK

by

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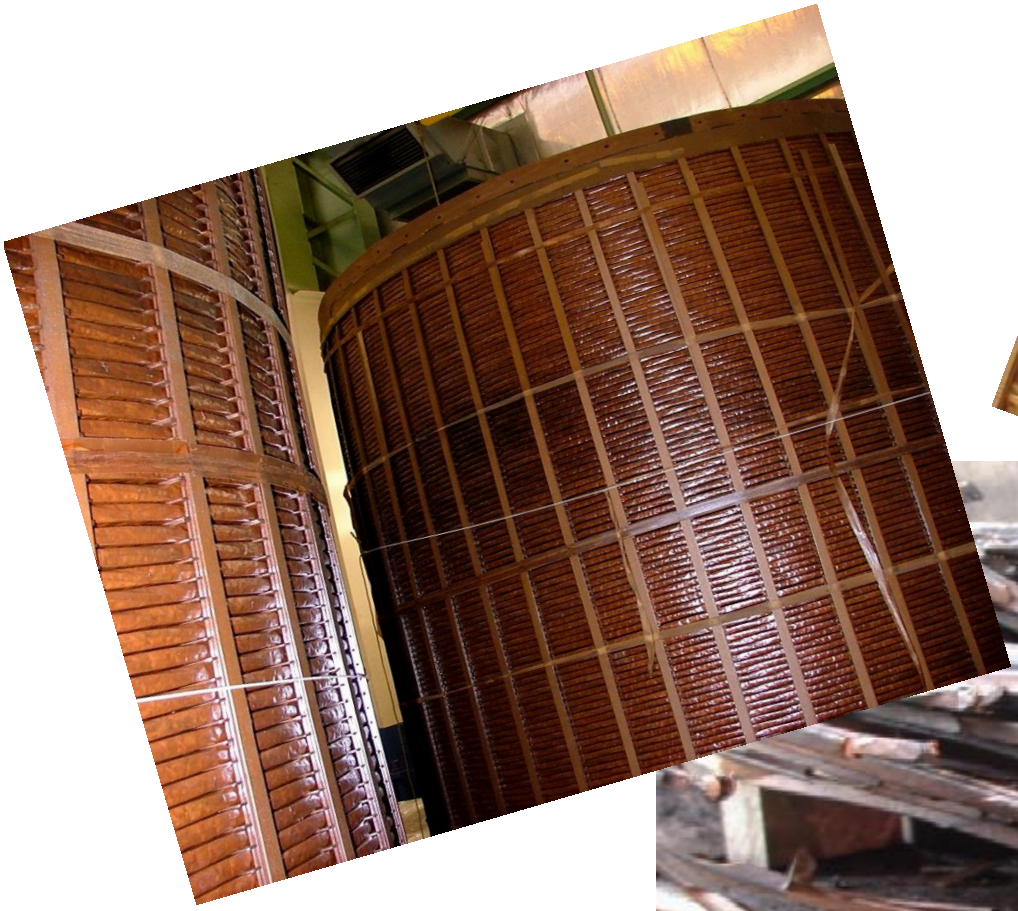
C. T. Gaunt, University of Cape Town

Eskom Generation

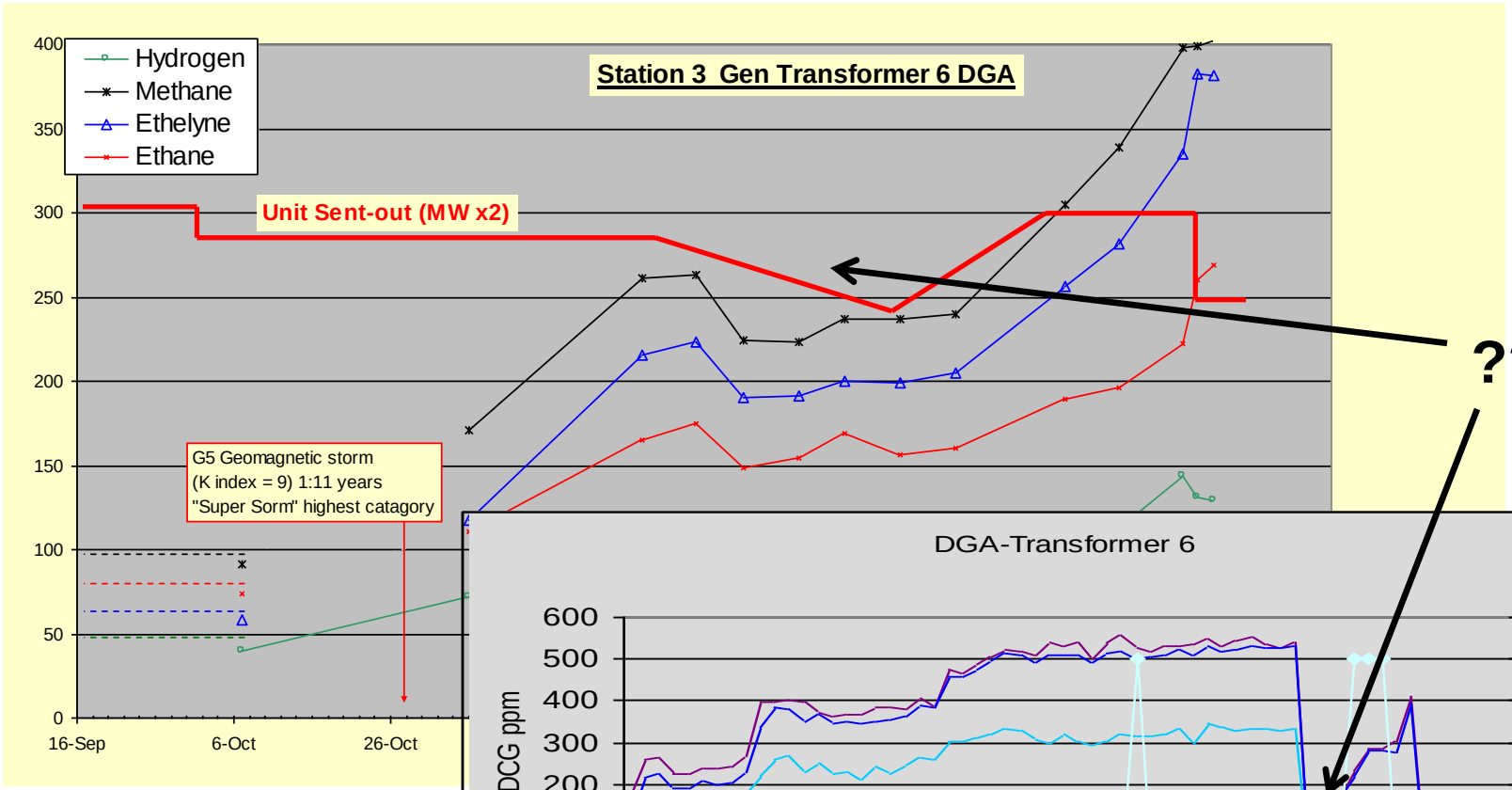
Halloween storm failures

29-31 Oct 2003	**2 ½ Day GMD (k = 9, A = 132)**
	Stn 3 trfr 4, Stn 3 trfr 6, Stn 2 trfr 1 **gases** start trending, severe damage
	Stn 3 trfr 1, Stn 3 trfr 2, Stn 3 trfr 3, Stn 3 trfr 5, Stn 2 trfr 1 and Stn 2 trfr 2 signs of damage on **DGA**
17 Nov 03	**Stn 4 trfr 6 trip on Generator transformer differential protection**
20 Nov 03	**Severe storm (k = 8, A = 98)**
23 Nov 03	**Stn 3 trfr 4 trip on differential protection**
12 Dec 03	**Stn 5 trfr trip on diff protection**

… and more failures



Dissolved Gas Analysis - DGA



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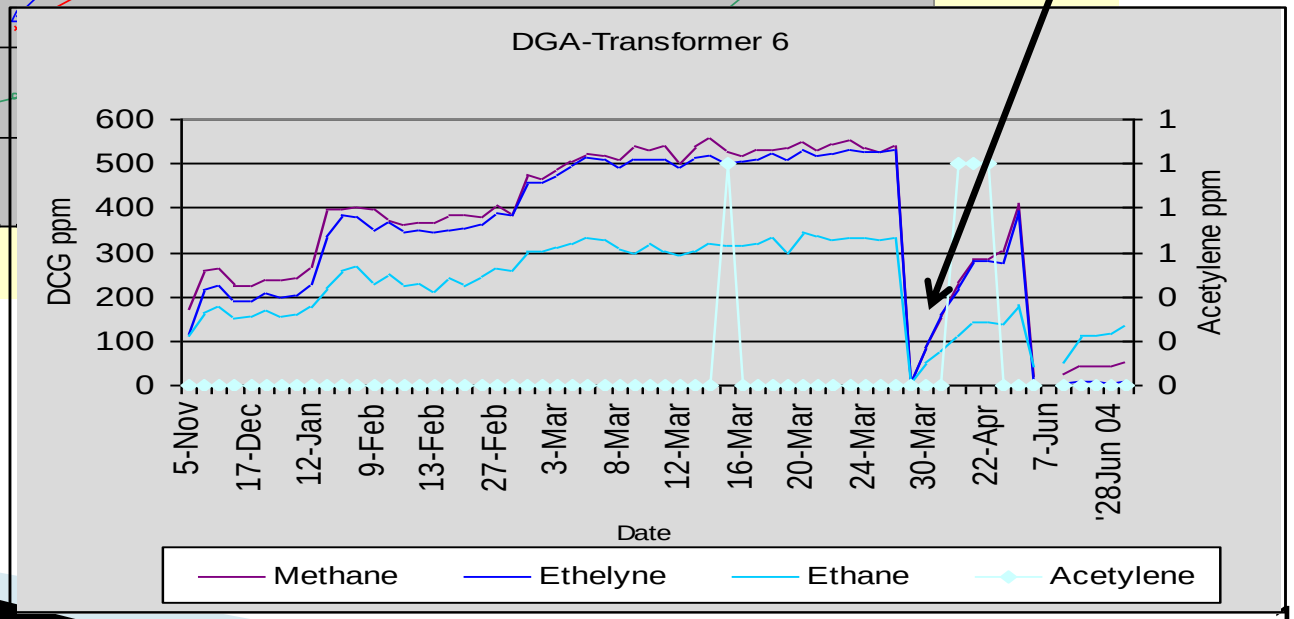


Degradation process

Initiated by over-heating:

- Overload
- Overvoltage and voltage distortion
- Flux distortion

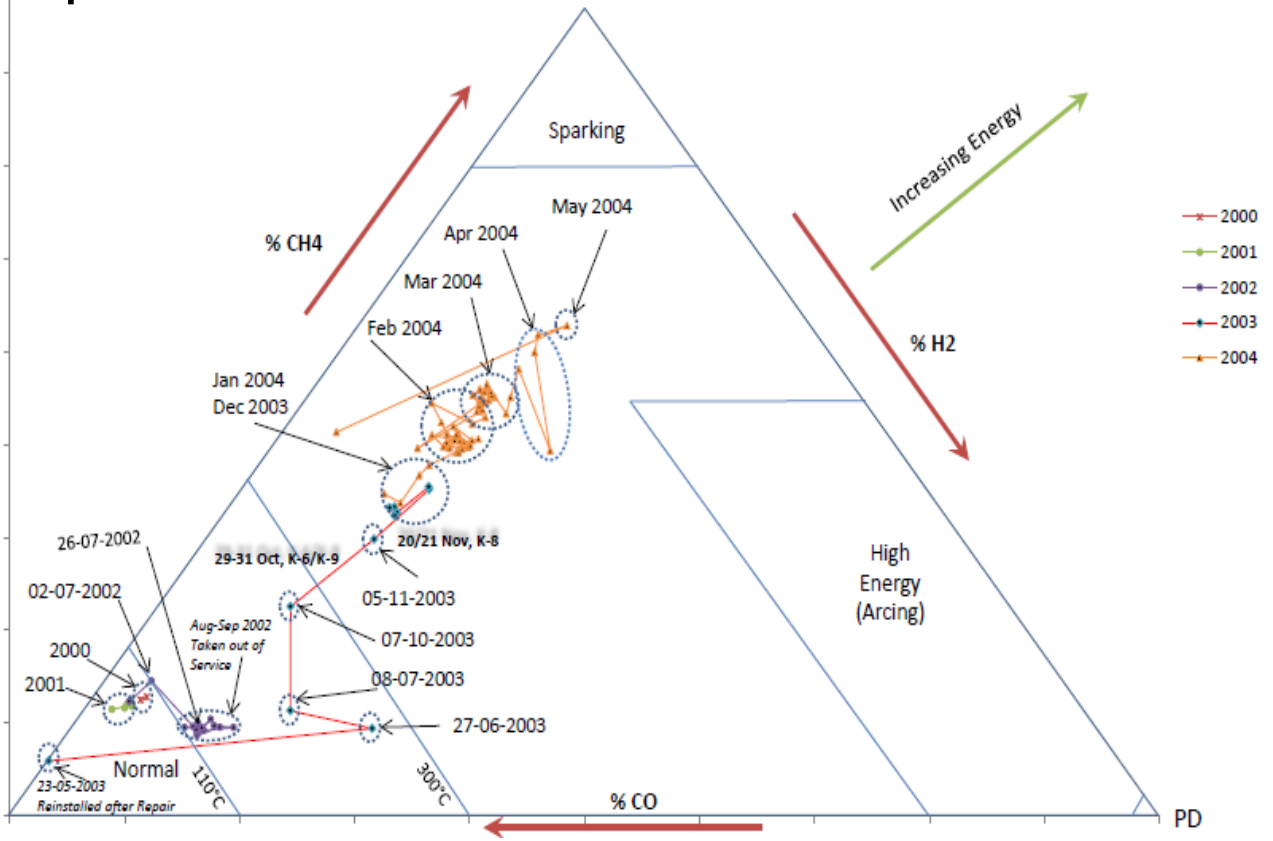
Depends on oil quality, paper condition, design and external influences.

Aggravated by moisture, bubble formation, quasi-DC, sulphur deposition.

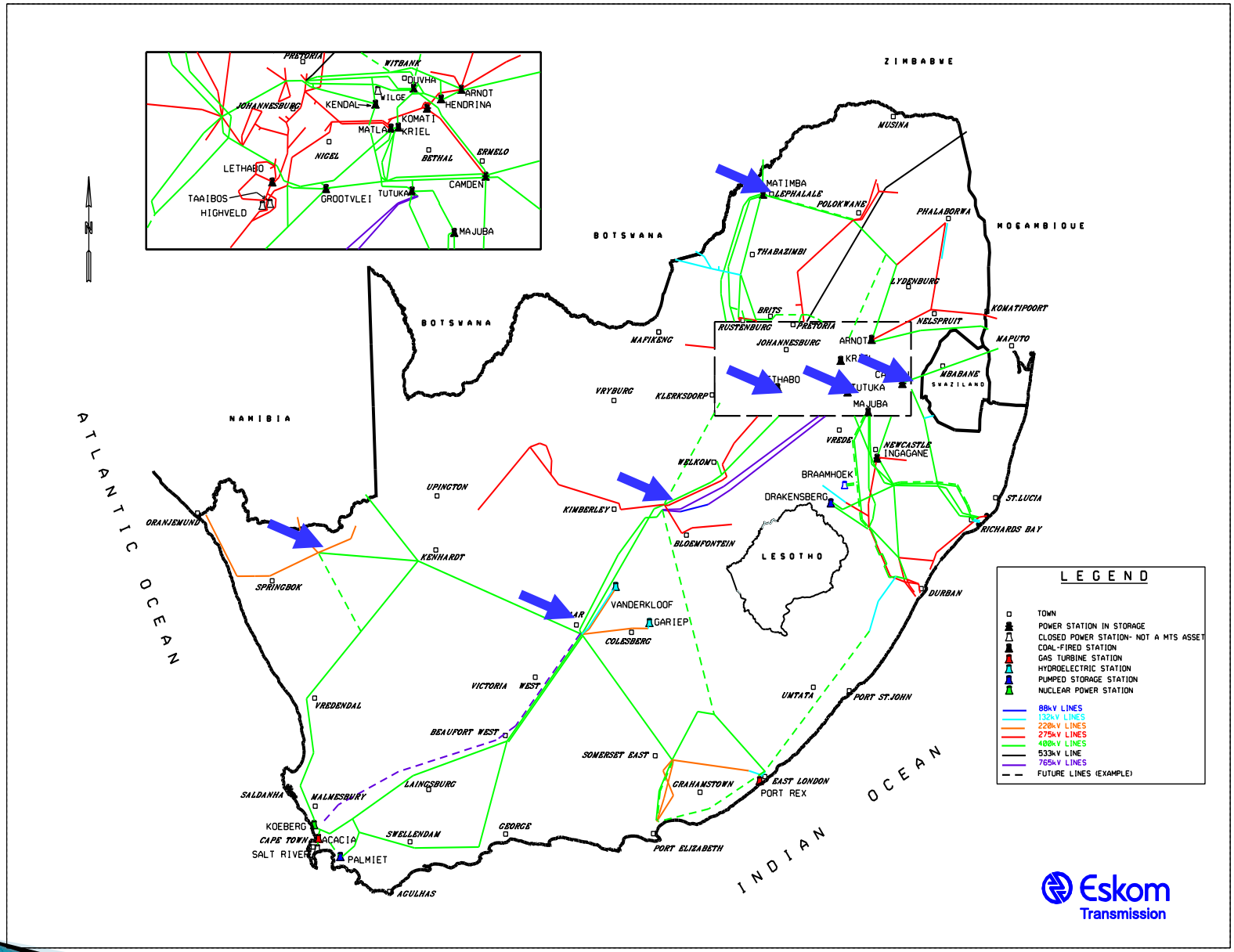
Transformer monitoring: DGA-LEDT

Low Energy Degradation Triangle of DGA shows transformer insulation degradation coincided with GMDs.

Consistent pattern for other South African transformers.

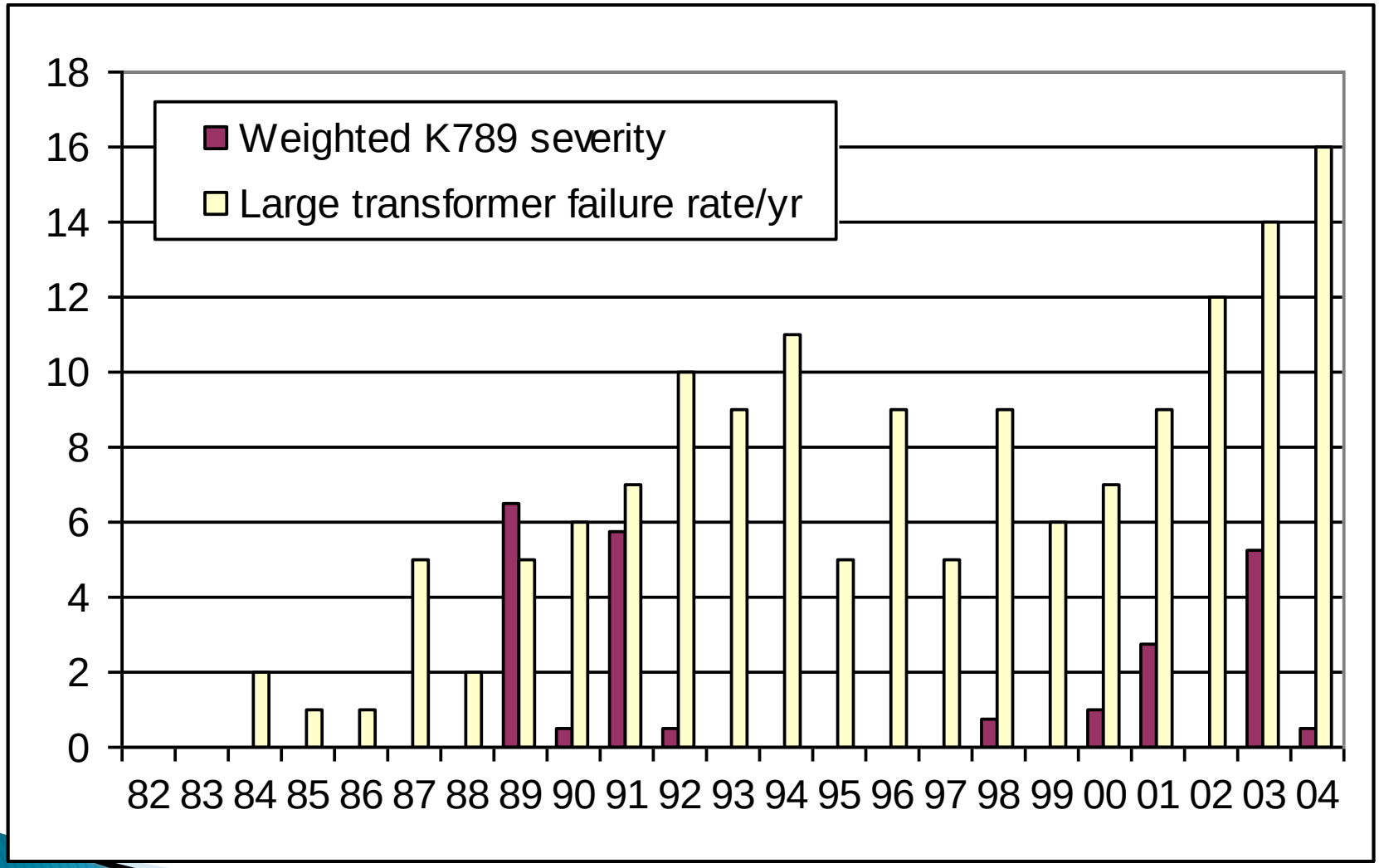


Moodley and Gaunt: IEEE PowerAfrica 2012



Transformer and reactor failure sites 2000-2003

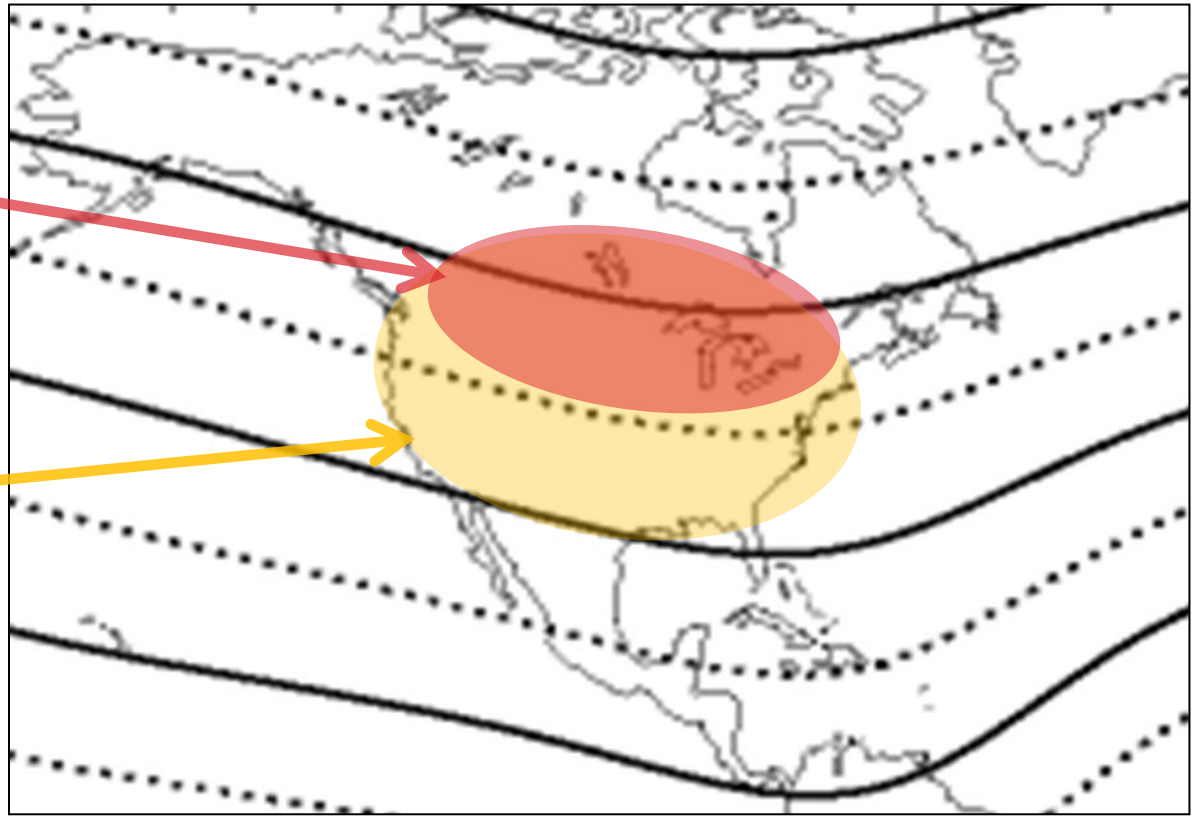
Transformer failures



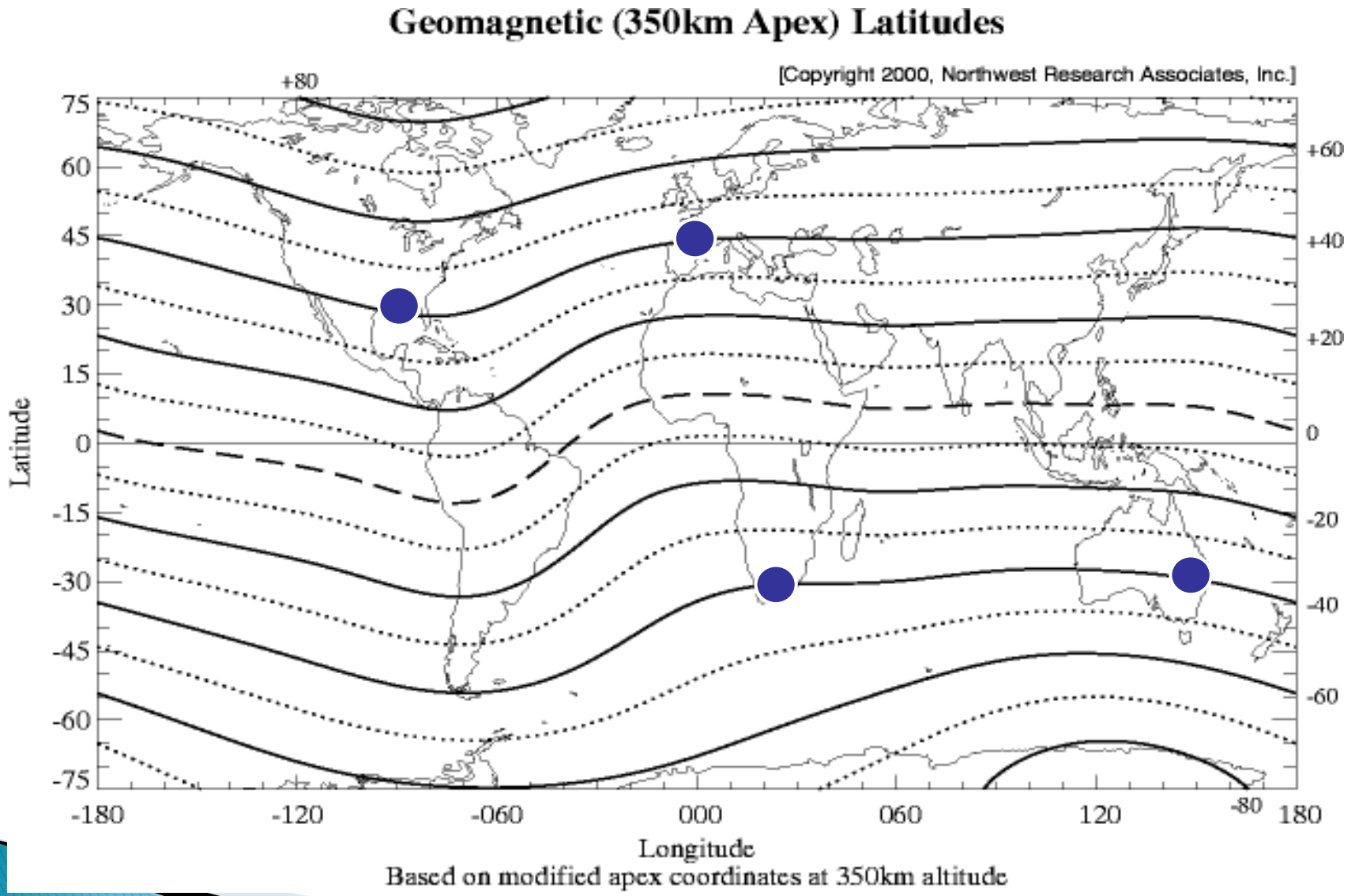
Two risk zones?

Extreme events: system collapse

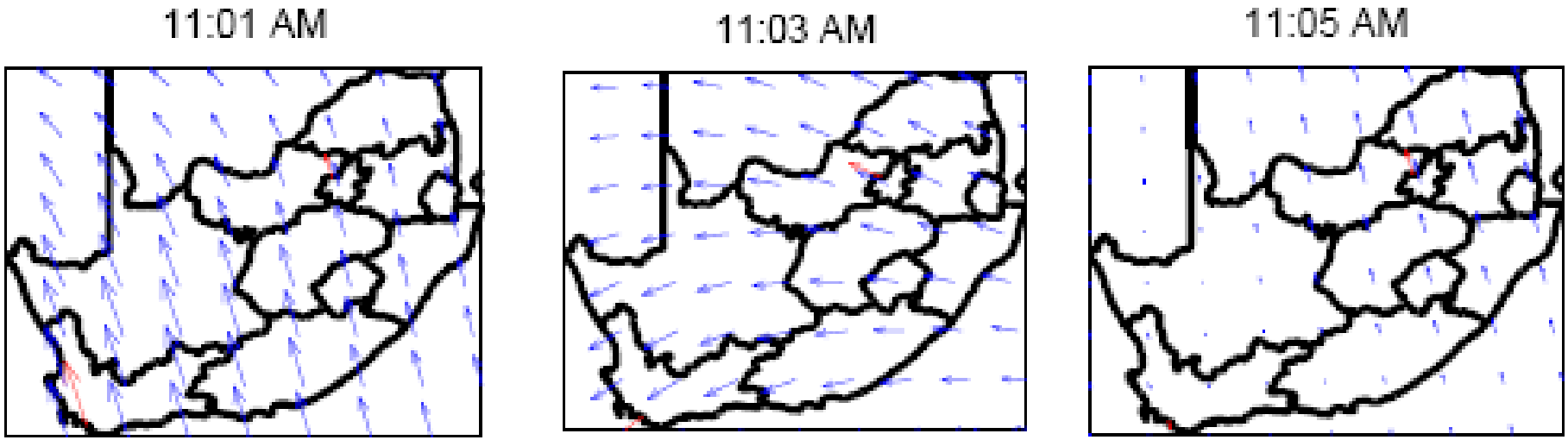
Severe events: equipment damage



Worldwide exposure

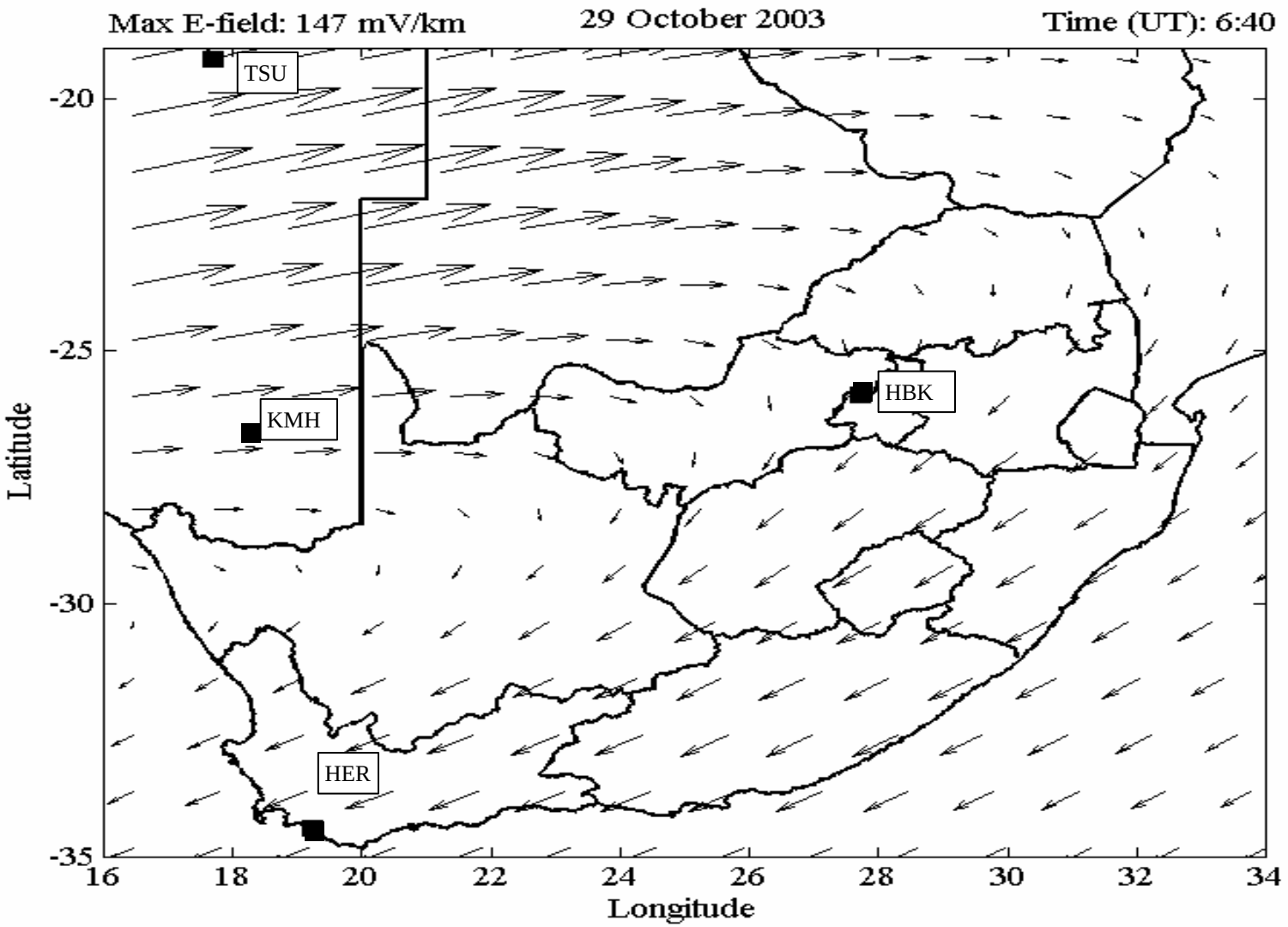


Field is not stationary



Interpolated dB/dt [Bernhardi, 2006]

Field is not uniform



[E Bernhardi, 2008]

Delayed transformer failure

Very different from the collapse scenario.

Relatively poor understanding of link between GIC (DC) and initiation of degradation.

Mitigation: Uncertain.

Want to know:

Duration, sub-storm fluctuation and energy in GIC events.

Transformer condition assessment.

Challenging questions

- Is mitigation less expensive than system or equipment failure?
- What is the range of **amplitudes** and **durations** of GMD events – including the extreme values?
- Can the engineers' **planning** models use the data from space weather forecasters?
- Can 18 / 18 / 18 warning be delivered to **system operators** by SWW'18?